Larry C. Munn, Ph.D.
Professor of Soil Science
Department of Renewable Resources
University of Wyoming
Laramie, WY 82071

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Interactions between Coal Bed Methane Product Water and Soils, Vegetation, Agriculture and Riparian Systems in the Powder River Basin.

I want to preface my comments with the recognition that the concepts presented in the following paragraphs are largely drawn from the extensive literature developed by the agricultural community through research and experience with irrigation. Irrigated agriculture is extremely important in meeting the world's food needs and there now exists several thousands of years practical experience and at least 100 years of science related to applying water to soils to enhance plant growth.

The CBM extraction process requires pumping of some of the water from the coal bed aquifers to de-pressurize the system and allow the methane to de-adsorb from the coal surfaces to be collected for processing and eventual shipment to market. There are several unique attributes of the CBM product water that must be recognized in attempting to utilize it to supplement plant growth, or if it is mixed with surface waters as a disposal method and those waters are later used for irrigation. The quantities of water involved are potentially large, with a single well initially producing perhaps 15,000 gallons of water per day at a rate of approximately 10 gallons per minute. This production will occur steadily over 365 days per year (including winter) and will total approximately 17 acre-feet of water annually. Since development of the resource may involve drilling 51,000 new wells over the next 15 years,(BLM, 2002), with perhaps 30,000 active at one time, the total quantity of water to be disposed of annually is expected to reach approximately 450,000 acre-feet.

Natural precipitation in the Powder River Basin is concentrated in the Spring, and many of the streams are ephemeral, carrying water only for short periods in response to snow melt and individual thunder storm events. Because CBM product water is produced evenly throughout the year, there will be large quantities of water produced during periods when plants are dormant and when the opportunity to dilute the CBM product water with stream flow water will be very limited. Some of the ephemeral streams may be converted to year around flow and this may present a situation where ice damming will cause flooding of land along the stream with undiluted product water. Year around flow will also raise local ground water tables under presently ephemeral channels and may slow infiltration from the channels, increasing runoff from individual storm events.

In addition to issues of quantity and timing, the major CBM water issues are related to the quality of the water- its salinity, sodicity and potential toxic elements. The coal bed aquifers have long been known to hold reserves of water of varying quality (Lupcho, 1998; Lowry and

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1987) and have been used extensively for livestock water and, to a lesser extent, human consumption.

The water extracted as a part of CBM production, the product water, has widely varying quality. In general, water quality is best in the area south of Gillette and decreases as you go across the Powder River Basin to the northwest towards Sheridan and up into Montana (BLM, 2001,2002). In the best water quality areas, the water is suitable for human and livestock use and for irrigation; in the areas with the poorer quality water, the water is unsuitable for growing plants and may even be problematic for watering beef cattle (Ayers and Westcot, 1985; Galey, 2002).

Salinity in water and soils is usually measured through evaluating the electrical conductivity of the water directly in the case of irrigation/drinking water and for a saturated extract from a soil sample. Typically, the conductivity is reported in units of micro-mhos per cm or as micro-Siemens per cm (micro-S/cm) in scientific publications. A milli-mhos per cm unit has also been used in the salinity literature; basically 1 milli-mho/cm is equal to 1000 micro-mhos/cm. The more salt that there is in a water sample, the more readily it conducts electricity and the higher the electrical conductivity (EC) value. Salinity may also be reported as total dissolved solids (TDS) but this is a more involved sampling process. There is a good, but not perfect, correspondence between EC and TDS. High salinity in the soil water reduces the ability of most plants to extract water from the soil. There is a greater energy cost to the plant to remove water from salt effected soils, and plants will typically wilt earlier in the day on salt effected soils, thereby decreasing photosynthesis and ultimately plant production. Salinity may also cause micro-nutrient deficiencies in crop plants (Rahman et al., 1994). At very high levels, salinity may cause direct toxicity to the plants.

Sodicity is a different, and often separate problem from salinity. High sodium in irrigation water, relative to calcium and magnesium, results in destruction of soil aggregation and loss of macro-pores at the soil surface. The loss of the larger soil pores through destruction of aggregation and the plugging of pores with dispersed clay particles greatly slows infiltration of water into the soil and ultimately reduces the water available for plant growth. Naturally occurring sodium affected soils are sometimes observed as "pan spots" on rangeland-they are typically sparsely vegetated and usually have a very hard consistence when dry. Soils with high clay content are most subject to the adverse effects of high sodium (sodicity)- particularly if the clay is of the high shrink-swell type (the smectite clay minerals, of which montmorillonite is one example). Sodicity of water is usually specified with a parameter called the Sodium Adsorption Ratio (SAR) which is calculated as the ratio of sodium (Na) to calcium (Ca) and magnesium (Mg) (Soil Salinity Laboratory Staff, 1954). The actual formula is: $SAR = Na/(\frac{1}{2}(Ca + Mg))^{\frac{1}{2}}$. An older "Rule of Thumb" was that Na would cause problems if there was 4X as much Na as Ca. Sodicity can be a problem at low SAR levels if the salinity of the water is low. For example, water with an EC of 500 micro-mhos/cm may cause dispersion problems and slow infiltration on clayey soils if the SAR is as low as 2. On the other hand, water with a salinity of 2000 micro-mhos/cm will not usually show infiltration problems until the SAR reaches levels above 10. The Colorado Cooperative Extension Service advises that water with an SAR above 10 should not be applied to crop fields (Follett and Soltanpour, 2001).

Soils in semi-arid environments such as the Powder River Basin typically have the smectite type clay mineralogy which is most affected by sodicity (Meshnick et al, 1977; Lupcho, 1998; Stephens, 1975; Reckner, 1986). While alluvium in the channels of the larger streams is commonly coarse textured, the soils used for crop production are the product of the deposition of finer sediments by over bank deposit during natural high water events. Soil textures in these fields are commonly heavy loams, clay loams and silty clay loams (Meshnick et al, 1977; Lupcho, 1998; Stephens, 1975; Reckner, 1986).

Because the CBM water has accumulated over long periods of time under a low oxygen environment in the coal seams, there is a concern that there may be particular elements in some of the water in concentrations which could be toxic. So far, barium is the only element which has been documented at levels in the water coming from CBM wells above established standards. Potentially there may be problems with other elements such as selenium, arsenic, and others; and the potential also exists for problematic levels of trace elements to build up as the product water is subject to evaporative loss and as it reacts with the soil and stream channel materials.

The literature developed from irrigation experience throughout the world (Ayers and Westcot, 1985; California Fertilizer Association, 1985; Soil Salinity Laboratory Staff, 1954) suggests that water with an electrical conductivity higher than 1300 micro-mhos/cm may cause salinity problems for sensitive crops on medium and fine textured soils. The effects of sodicity varies with the salinity level of the water because high salinity counters the negative effects of the Na on infiltration However, this effect is only useful in irrigation if the salinity is within the level allowable for the crop to be grown, and if it is possible to adequately leach the soil profile to keep sodium from building up through continual water additions over time. Some crops can stand much higher salinity levels than others without experiencing yield reductions. Wheat for example exhibits a threshold for yield reduction when the average salinity in the irrigation water (ECw) reaches 4000 micro-mhos/cm. Alfalfa is relatively sensitive to salinity and its yield loss threshold is 1300 micro-mhos/cm; the threshold for corn is 1200. CBM water from Wyoming wells in the Powder River Basin has been measured with EC's as low as 500 micro-mhos/cm and as high as 3000. SAR's have been observed to range from less than 2 to 50 or higher (BLM, 2002).

Salinity tends to build up in the soil over time as salty water is added repeatedly (Hanson et. al, 1999). Water is lost from the soil through plant transpiration and by evaporation from the surface. If irrigation is to be sustained, the irrigators must add additional water above the needs of the crop to leach excess salts from the root zone. This is commonly referred to as the "leaching requirement". If enough water is added to provide 15 to 20% above the needs of the crop for leaching, the average salinity of the soil extract (ECe) will stabilize at about 1.5 times the EC of the irrigation water (ECw). Thus an ECw threshold of 1300micro-mhos/cm for yield reduction in alfalfa corresponds to a soil salinity level (ECe) of 2000micro-mhos/cm. If water is used which has an ECw of 2000 micro-mhos/cm, the soil EC (ECe) in the root zone would build up to 3000 micro-mhos/cm within a few years (assuming an 15% leaching requirement). If the soil has very slow permeability or other restriction on internal drainage, salinity will continue to build up in the soil over time, eventually prohibiting plant growth. In practice farmers typically use low leaching percentages with good quality water and higher leaching percentages for saltier water.

Because of the long history of use and data base in the literature, EC and SAR are likely to continue to be the parameters of choice with which to evaluate water and soils for irrigation suitability. The values used as guidelines for irrigation water quality in the USA are primarily those developed by the agricultural support community, including such sources as the National Soil Salinity Laboratory in Riverside California (Soil Salinity Laboratory Staff, 1954), the Agricultural Research Service, the Co-operative Extension Service (Follett and Soltanpour, 1999; Hanson et al., 1999; Carter, 1969) and the Colleges of Agriculture at the Land Grant Universities in the Western States (Hergert and Knudson, 1997; Vomicil and Hart, 1998), and such private organizations as the California Fertilizer Association (California Fertilizer Association. 1985). In the Powder River Basin, interpretation of the suitability of a particular water and prediction of the likely outcomes if it is applied to the landscape needs to be made with full understanding of the soil depth and internal drainage characteristics of the landscape. Irrigation without salinity buildup is relatively easy on floodplains with soils underlain by alluvial gravels. It becomes much more difficult on soils underlain by fine sediments or on uplands underlain by soft sedimentary bedrock as is the case for most of the Powder River Basin landscape. Most upland soils in the Powder River Basin have soft bedrock contact at between 50 cm. and 150 cm (Meshnick et al, 1977; Lupcho, 1998; Stephens, 1975; Reckner, 1986).

Installation of perforated plastic pipe drains facilitates removal of salinity from the fields and additions of gypsum help counter the effects of high sodicty in soils and irrigation waters (Rhodes, 1982). Both are costly in a cropping system where growing seasons severely limit crop selection and yields. Because of a more favorable climate and the availability of greater acreage on a broader floodplain, there is considerably more development of irrigated agriculture in Montana then in Wyoming along the streams in the PRB. There were 72,010 acres of irrigated crops harvested in Big Horn, Rosebud and Powder River Counties, Montana in 2000 as compared to 45,000 acres of irrigated hay in Sheridan and Campbell Counties, Wyoming in 1999. Average yields for irrigated alfalfa in northeast Wyoming are 2.6 tons/acre; grass hay averages 2.2 tons/acre (Wyoming Agricultural Statistics 2000). Average hay yields in the Montana PRB are somewhat higher at3.7 tons/acre for irrigated alfalfa in Big Horn County and 3.4 tons/acre in Rosebud County in 2000 (Montana Agricultural Statistics, 2001). The economics of the system thus limits the level of management inputs practiced by the operators. Most of the hay produced in the Wyoming PRB and much of the hay produced in Montana is used by the ranchers for winter feeding of their cattle. This hay is critical to their ability to support their herds over the winter (Barsh, 1990) and the purchase of hay is a major cash expense for many operators. Reductions in hay yield or quality would therefore have a significant negative impact on these operators.

The numbers published as guidelines for irrigation water quality are conditional in that the success of the irrigation effort in large part depends upon the skill and effort of the operator. In general, it is possible to use increasingly poor quality water as the value of the crop and length of the growing season increase. When salinity reaches a crop dependant threshold level, additional increments of salinity will result in decreased yields; this decrease is generally inversely linear with increasing salt load. Precipitation **as rain** in the non-growing season is important for leaching salts from the fields in many irrigated areas of the world (e.g the Mediterranean area, Southern California) where saline waters are used to produce crops. In the PRB, winter precipitation occurs almost exclusively as snow which limits leaching of last year's salt accumulation from the fields until the river rises with snow melt in the spring and irrigation water becomes available. As water quality deteriorates, it becomes ever more important that the soil have unrestricted internal drainage throughout the root zone to allow leaching water to flush salts from at least the upper portion of the plant root zone. Irrigation for only a few years with high quality water will result in salinity build up on soils with restricted internal drainage in climates where evapo-transpiration demand exceeds precipitation (Keren, 2000; Hanson et al., 1999). The major negative effect of high sodicity in irrigation water is to reduce infiltration rates and permeability of the soil, thereby preventing effective infiltration of irrigation water and precipitation, and to limit leaching of salinity from the root zone (Levy, 2000). High sodium content in irrigation water makes it difficult for the irrigators to achieve good water distribution and results in increased salinity problems in only a few years. Crusting which limits germination success is also a problem enhanced by high sodium levels.

Thresholds for reduction in crop yield are commonly reported both as conductivity of the irrigation water (ECw) and as conductivity of the saturated paste extract (ECe). It is important to understand which parameter is being specified since the threshold ECe is typically 1.5 times or greater higher than corresponding ECw. It must be kept in mind that most crop plants are grown in soils at field capacity and significantly drier. Hence, the ECw and ECe values will be lower than the actual EC (salinity) of the soil solution in the root zone between irrigations. For example, the Nebraska Co-operative Extension Service (Hergert and Knudson, 1977) state than an ECw of 1 dS/m would result in soil water film EC's of 2 dS/m or higher. Ayers and Westcot (1985) list ECw values of 1100 micromhos/cm for corn and 1300 micromhos/cm for alfalfa as threshold values for yield reductions due to general salinity effects with good management.

Research with alfalfa irrigation in the Powder River Basin has shown that the crop typically can effectively utilize about 22 inches of water in addition to natural precipitation, with additional water required to achieve the desired leaching fraction. Typical irrigation may involve addition of a total of about 30 inches of water. Other crops and most of the native vegetation in the basin will utilize less water and this limits the effectiveness of using plants to dispose of the product water through consumptive use. Where large quantities of water are applied to the soil with an intent to allow plant transpiration and evaporation to dispose of the water, the total amount of salt added will quickly limit plant growth. Water with 1300 micro-mhos/cm conductance contains approximately 830 ppm TDS. Each acre foot of this water will add 1.2 tons of salt (per acre). This explains why the leaching requirement exists even for high quality water.

Except for very limited areas of naturally saline soils which are tied to particular bedrock conditions or landscape position, the soils of the PRB have received additions only of rainfall and snowmelt waters with very low salt contents. The salt load of even the best of the CBM product water will prove damaging to the native vegetation or common crops of the area unless good water management including leaching of the salt from the root zone annually is achieved (Bernstein, 1964). Relatively small areas of the PRB landscape is naturally saline (Meshnick et al, 1977; Lupcho, 1998; Stephens, 1975; Reckner, 1986). Because many of the soils in the PRB are clayey, and many are shallow or only moderately deep, additions of large amounts of product water will not be practical. In a semi-arid climate, regular additions of even small increments of water may redistribute natural salinity on the landscape, as has been documented for the saline seeps associated with the crop/fallow system of wheat production in Montana, the Dakotas and Canadian prairie provinces (Ferguson and Bateridge, 1982). The use of atomizers aids disposal of the water, but will only concentrate the salt. While conveyance loss from individual storm events is large in ephemeral streams in the PRB (Petroleum Association of Wyoming, 2001; Hydrologic Consultants, Inc., 2000; Lenfest, 1987), conveyance loss will decrease as the streams become perennial and water which soaks into the alluvial aquifer high in the watershed will interact with surface waters lower in the watershed (Petroleum Association of Wyoming, 2001; Hydrologic Consultants, Inc., 2000; Lenfest, 1987) with the potential to affect downstream irrigators (Horpestad et al., 2001).

Recent research suggests that some values of salinity acceptable in stock water in the literature are too high, if yield loss is to be avoided. Yield reductions can be expected in beef cattle when sodium levels reach a threshold of 2500 ppm, depending upon the mineral content of the feed (Dr F. Galey, DVM, Dean College of Agriculture, University of Wyoming, personal communication, February 2002). Also, high Mg in the water (greater than 250 ppm) may make Na toxic to livestock at a lower threshold. Some water from coal seams in the northern part of the PRB shows high levels of Mg, in some cases greater than 250 ppm(Davis, 1984). High Mg relative to Ca may also cause similar slow infiltration problems as those induced by high Na (Soil Survey Staff, 1999).

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